COSMIC SUPERNOVA RATE HISTORY AND TYPE IA SUPERNOVA PROGENITORS

C. KOBAYASHI[1], K. NOMOTO[1], and T. TSUJIMOTO[2]
[1] *Department of Astronomy, School of Science, University of Tokyo, Bunkyo-ku, Tokyo 113-0033, Japan*
[2] *National Astronomical Observatory, Mitaka, Tokyo 181-8588, Japan*

Adopting a single degenerate scenario for Type Ia supernova progenitors with the metallicity effect, we make a prediction of the cosmic supernova rate history as a composite of the supernova rates in spiral and elliptical galaxies, and compare with the recent observational data up to $z \sim 0.55$.

1 Metallicity Effects on Type Ia Supernova Progenitors and Chemical Evolution of Galaxies

We adopt a single-degenerate (SD) scenario, which assumes that a C+O white dwarf accretes H-rich meterials from the binary companion star and grows its mass to the Chandrasekhar mass to explode as a Type Ia supernova (SN Ia). There are two progenitor systems: One is a red-giant (RG) companion with the initial mass of $M_{\rm RG,0} \sim 0.9 - 1.5 M_\odot$ and an orbital period of tens to hundreds days [1 2 3]. The other is a near main-sequence (MS) companion with an initial mass of $M_{\rm MS,0} \sim 1.8 - 2.6 M_\odot$ and a period of several tenths of a day to several days [4 3]. Optically thick winds from the mass accreting WD play an essential role in stabilizing the mass transfer and escaping from forming a common envelope. Since the optically thick winds are driven by a strong peak of iron lines, the occurrence of SNe Ia depends strongly on the iron abundance. If the iron abundance is as low as [Fe/H] $\lesssim -1.1$, then the wind is too weak for SNe Ia to occur [5].

Our model successfully reproduces [O/Fe]-[Fe/H] relation observed by oxygen forbidden lines, which has a constant [O/Fe] of ~ 0.45 at [Fe/H] $\lesssim -1$ and a decrease in [O/Fe] with increasing metallicity. If we do not include the metallicity effect, the largest companion star with $M \sim 2.6 M_\odot$ produce SNe Ia at the age of ~ 0.5 Gyr and decrease [O/Fe] too early to be compatible with the observations. For the metallicity dependent SD scenario, SNe Ia occur at [Fe/H] $\gtrsim -1$, which naturally reproduce the observed break in [O/Fe] at [Fe/H] ~ -1 [5].

We construct the galaxy models to meet the latest observational constraints of chemical and photometrical properties, and can reproduce the present

supernova rates in the galaxy. For spirals, owing to the presence of the *two* kinds of the SN Ia progenitor systems (MS+WD and RG+WD) with shorter ($0.5-1.5$ Gyr) and longer lifetimes ($2-20$ Gyr), respectively, we can explain the difference in the relative ratio of the SN Ia to SN II rate $\mathcal{R}_{\rm Ia}/\mathcal{R}_{\rm II}$ between early and late types of spirals. For ellipticals, owing to the presence of the RG+WD systems with over 10 Gyr lifetime, SNe Ia can be seen even at present in ellipticals where the star formation has already ceased more than 10 Gyr before because of a supernova-driven galactic wind [6].

2 Cosmic Supernovae Rate

Galaxies that are responsible for the cosmic SFR have different timescales for the heavy-element enrichment, and the occurrence of supernovae depends on the metallicity therein. Therefore we calculate the cosmic supernova rate by summing up the supernova rates in spirals and ellipticals with the ratio of the relative mass contribution [6]. Here we adopt $H_0 = 65$ km s^{-1} Mpc^{-1}, $\Omega_0 = 0.3$, $\lambda_0 = 0.7$, and the formation epoch of $z_{\rm f} = 5$.

Figure 1 shows the cosmic supernova rates in cluster galaxies. The SN Ia rate in spirals drops at $z \sim 1.9$ because of the low-metallicity inhibition of SNe Ia. We can precisely test the metallicity effect by finding this drop of the SN Ia in spirals, if high-redshift SNe Ia at $z \gtrsim 1.5$ and their host galaxies are observed with the Next Generation Space Telescope. In ellipticals, the chemical enrichment takes place so early that the metallicity is large enough to produce SNe Ia at $z \gtrsim 2$. The two peaks of SN Ia rates at $z \sim 2.6$ and $z \sim 1.6$ come from the MS+WD and the RG+WD systems, respectively. The SN Ia rate in ellipticals decreases at $z \sim 2.6$, which is determined from the shortest lifetime of SNe Ia of ~ 0.5 Gyr. Thus, the total SN Ia rate decrease at the same redshift as ellipticals, i.e., $z \sim 2.6$.

We also predict the cosmic supernova rates assuming that the formation of ellipticals in field took place for over the wide range of redshifts, which is imprinted in the observed spectra of ellipticals in the Hubble Deep Field. The adopted SFRs are the same as the case of cluster galaxies, but for the formation epochs $z_{\rm f}$ of ellipticals distribute in the range of $0 \leq z \leq 5$. Figure 2 shows the cosmic supernova rates in field galaxies. As in Figure 1, the SN Ia rate in spirals drops at $z \sim 1.9$. The averaged SN Ia rate in ellipticals decreases at $z \sim 2.2$ as a result of ~ 0.5 Gyr delay of the decrease in the SFR at $z \gtrsim 3$. Then, the total SN Ia rate decreases gradually from $z \sim 2$ to $z \sim 3$.

Although the error bars are large, there is a hint that the observed SN Ia rate decreases from $z \sim 0.4$ to the present. If this is confirmed, it could imply that the rate of SNe Ia from long-lived $0.9M_\odot$ companions is lower than

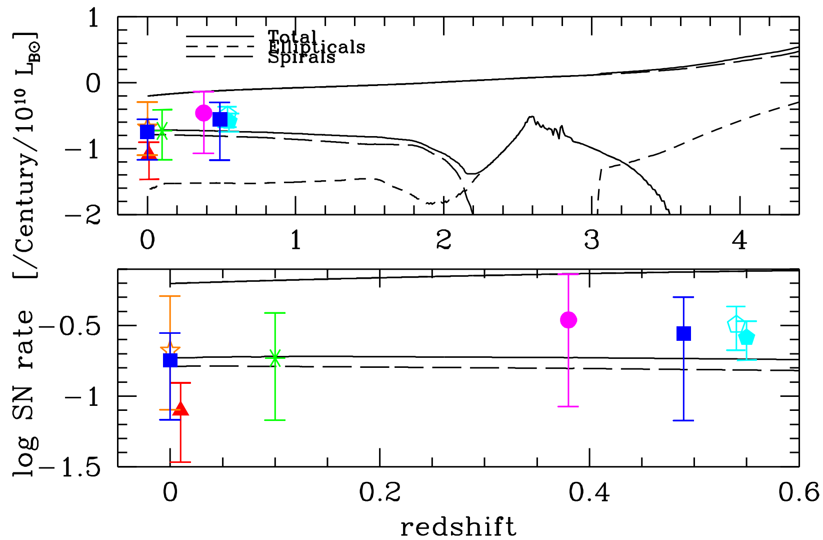

Figure 1: The cosmic supernova rates (solid line) as the composite of ellipticals (short-dashed line) and spirals (long-dashed line). The upper three lines show SN II rates, the lower three lines show SN Ia rates. Observational data sources: triangle [7], star [8], asterisk [9], circle [10], open pentagon [11], closed pentagon [12], and square [13]

that assumed in our model. From $z \sim 0.4$, the observed SN Ia rate seems to slightly decrease toward higher redshifts. To discuss their implications in terms of the progenitors' evolution, we should exclude the luminosity uncertainties in the unit of supernova rates and introduce more detail galaxy models including internal structure of a galaxy and galaxy number evolution.

The rate of SNe II in ellipticals evolves following the SFR without time delay. Then, it is possible to observe SNe II in ellipticals around $z \sim 1$. The difference in the SN II and Ia rates between cluster and field ellipticals reflects the difference in the galaxy formation histories in the different environments.

3 Discussion

We make the following predictions that can test this metallicity effect. 1) SNe Ia are not found in the low iron abundance environments such as dwarf galaxies and the outskirts of spirals. 2) The SN Ia rate in spirals drops at $z \sim 2$ due to the low-iron abundance, while SNe Ia can be found at $z \gtrsim 2.5$ in cluster ellipticals, where the timescale of metal enrichment is sufficiently short. 3) If the formation of field ellipticals is protracted to lower redshifts, the SNe Ia

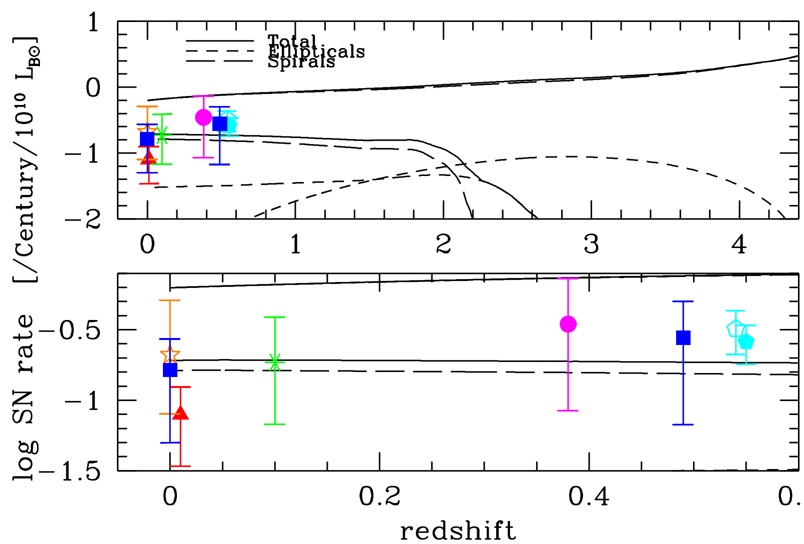

Figure 2: The same as Figure 1, but for the formation epochs of ellipticals span at $1 \lesssim z \lesssim 4$, which corresponds to field ellipticals.

rate decreases from $z \sim 2$ in the field ellipticals.

Our predicted cosmic SN Ia rate is consistent with the recent observation within error bars up to $z \sim 0.55$. If stronger dependences on redshifts are found, it would provide important constraints on the mass-range (i.e., lifetime) of the WD's companions and metallicity effects.

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